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Title: Module 6 Flattop-Free Run Demonstration

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Intended for: This presentation will be used as part of handout of modules that students get when they take the Nuclear Criticality Safety training given in Nevada

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NUCLEAR CRITICALITY
SAFETY PROGRAM

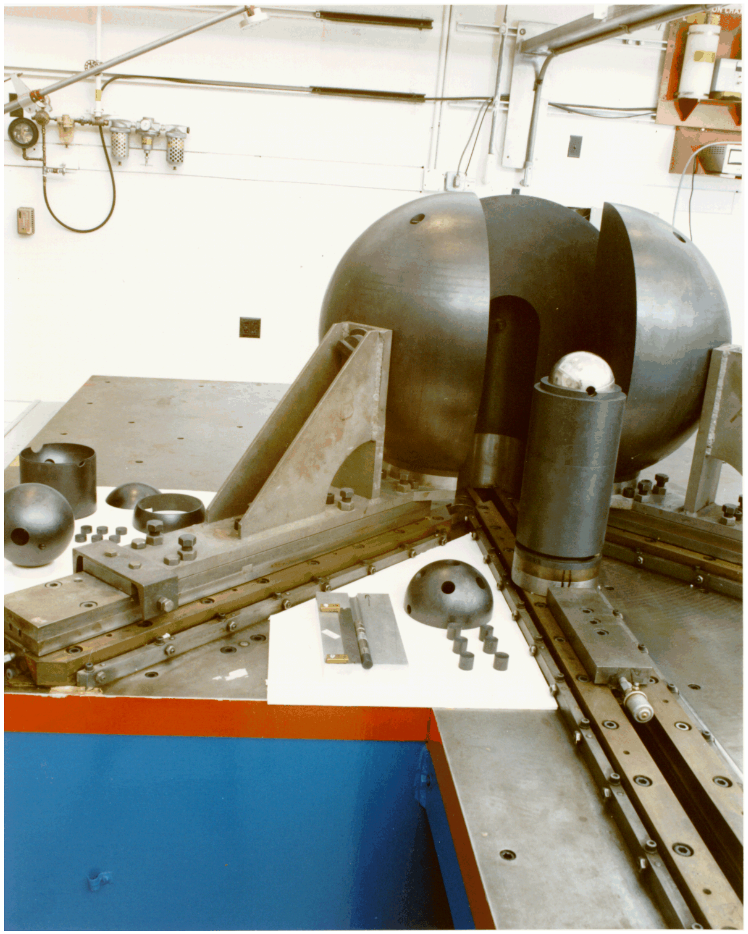
Module 6
Flattop Free-Run Demonstration

LA-UR-21
Unclassified

Goals

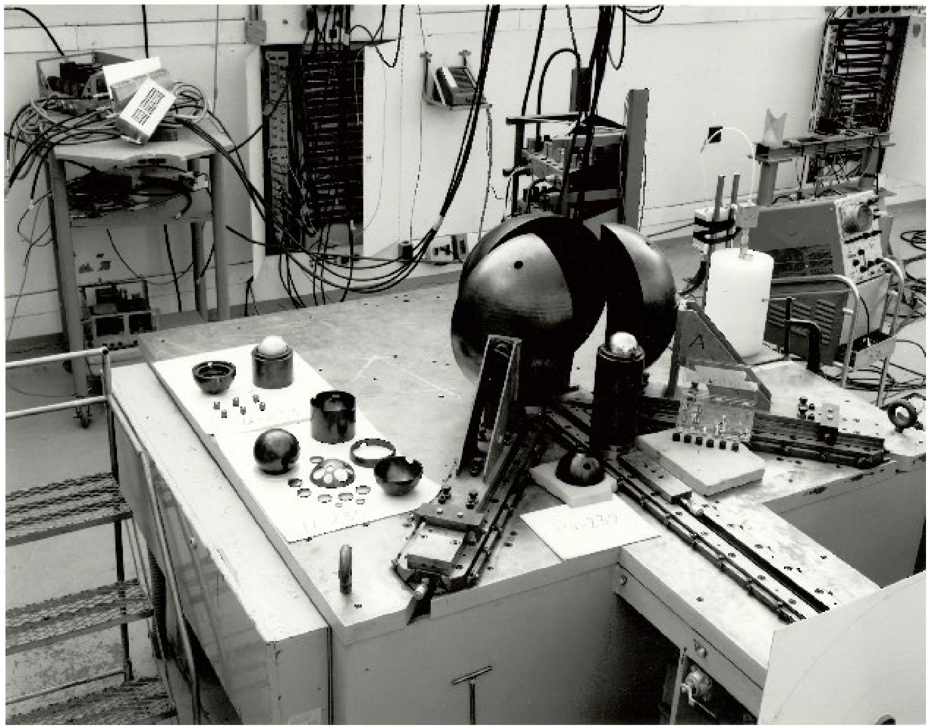
- To ensure students gain a working knowledge of the design of the Flattop critical assembly.
- To ensure students gain a working knowledge of how changes in reflector geometry can affect the criticality of a system.
- To ensure students gain a working knowledge of how to use the Inhour equation and associated parameters to infer the reactivity addition during a transient excursion.
- To ensure the students gain a working knowledge of the concept of temperature-dependent reactivity feedback as it applies to the transient behavior of a critical assembly during a nuclear excursion.

Flattop Assembly General Description



- Simple one-dimensional spherical geometry benchmark assembly.
- Used originally for critical mass studies for thick uranium reflected systems in spherical geometry.
- 1000-kg natural uranium reflector (0.7 wt % ^{235}U, 19.0 g/cm^3)
  - 500-kg hemisphere.
  - Two 250-kg quarter-sphere safety blocks.
  - Reconfigurable pedestal to accommodate different cores.
- Can operate in "free-run" mode up to several kilowatts
  - Temperature increases of up to 300˚C

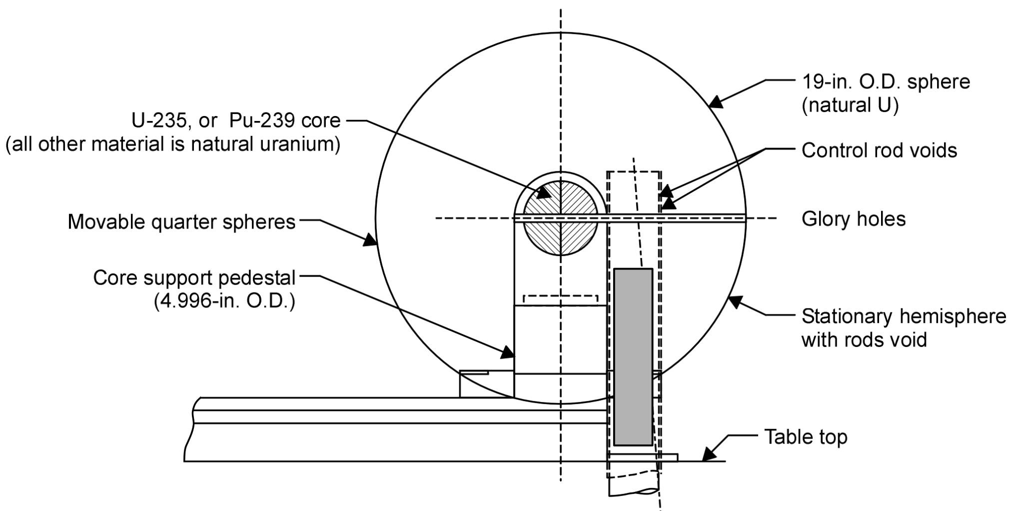
Flattop Assembly General Description



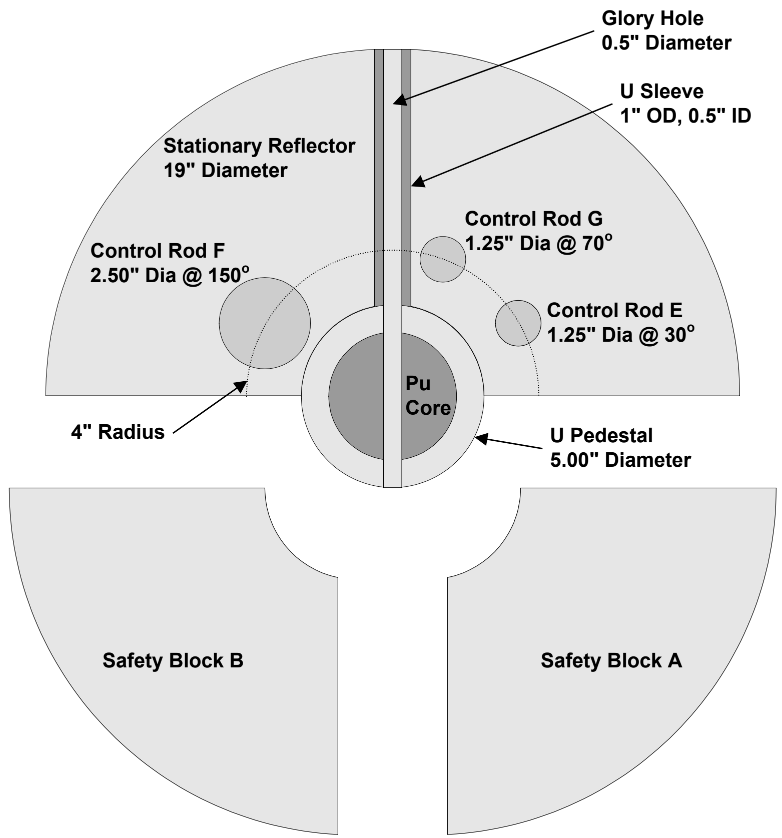
Flattop in Kiva II at Pajarito Site in Los Alamos, circa 1964.

- Currently, two basic cores are available for use with assembly:
  - uranium (93.24 wt % ^{235}U metal core).
  - plutonium (4.8 wt % ^{240}Pu) delta-phase metal core clad in nickel.
- Other core configurations used in past studies include
  - a ^{233}U metal core and
  - composite plutonium/uranium metal cores.
- Current applications include
  - sample reactivity worth studies,
  - reactor dynamic excursion studies,
  - sample neutron activation studies,
  - dosimetry measurements,
  - critical assembly operator training, and
  - criticality safety training demonstrations.

Flattop Core Design

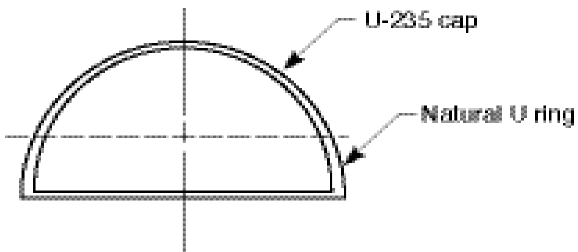


Elevation View

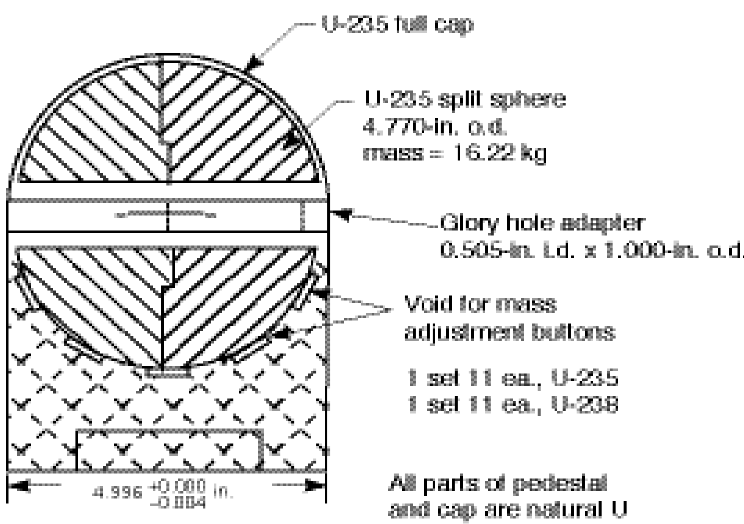


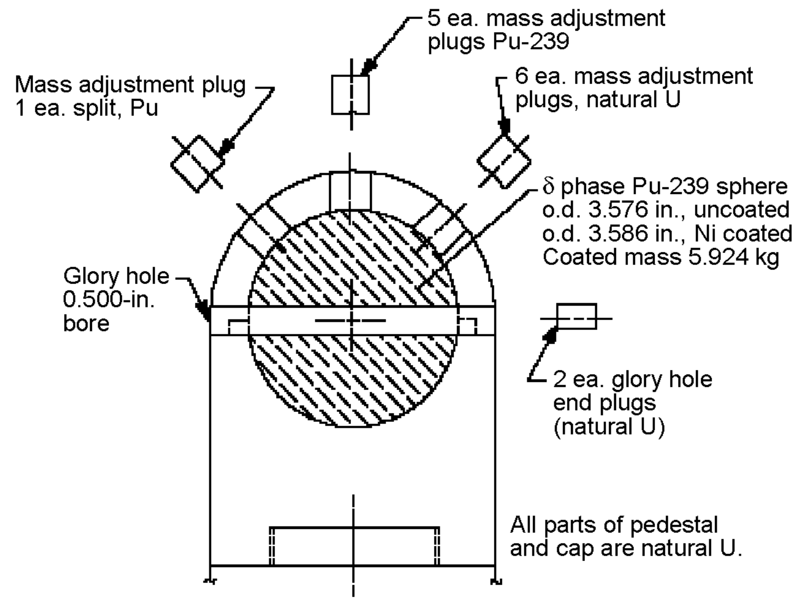
Pu Core: 3.57" Diameter
U Core: 4.77" Diameter
Rod Diameters are 13 mils less than the shown hole sizes

Flattop Core Design



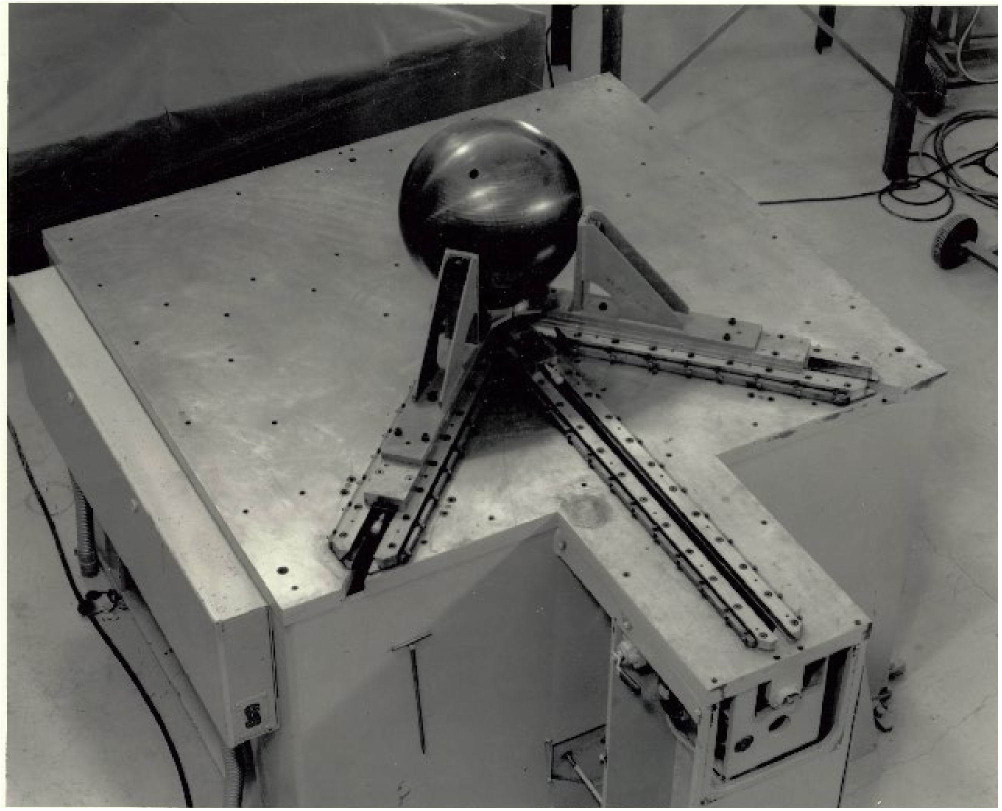
Split Cap Alternative No. 1





Uranium Core Material Description

- The highly enriched uranium (HEU) metal core is composed of
  - 93.24 wt % ^{235}U,
  - 5.74 wt % ^{238}U, and
  - 1.02 wt % ^{234}U.
- The core uranium density is 18.62 g/cm^3.



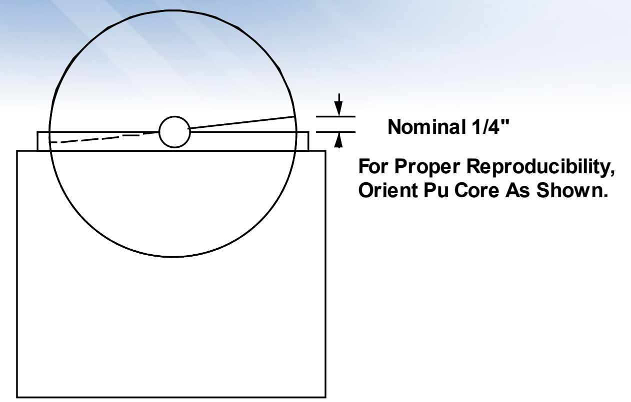
Flattop Critical Assembly, circa 1958.

Plutonium Core Material Description

- The Flattop plutonium core consists of two hemispheres of delta-phase plutonium (4.8 wt % ^{240}Pu) metal alloy clad in nickel (avg. 0.005-in.-thick nickel clad).
- The core density is 15.53 g/cm^3.
- The total plutonium mass in the two halves is just under 6 kg.

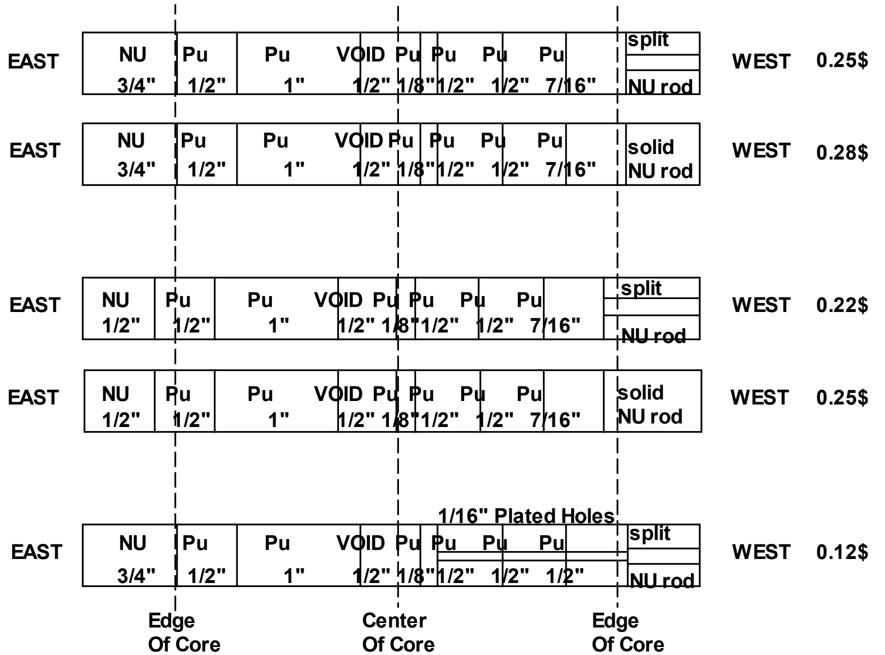
Flattop Core Design

Orientation of plutonium hemispheres for reproducibility.



Examples of glory hole loadings and their excess reactivities when using the plutonium core.

Nominal Reactivities for Pu Core/ 6 NU Buttons In Cap/ Glory Hole as Follows:
(Measured September/October 1999)



Flattop Control System

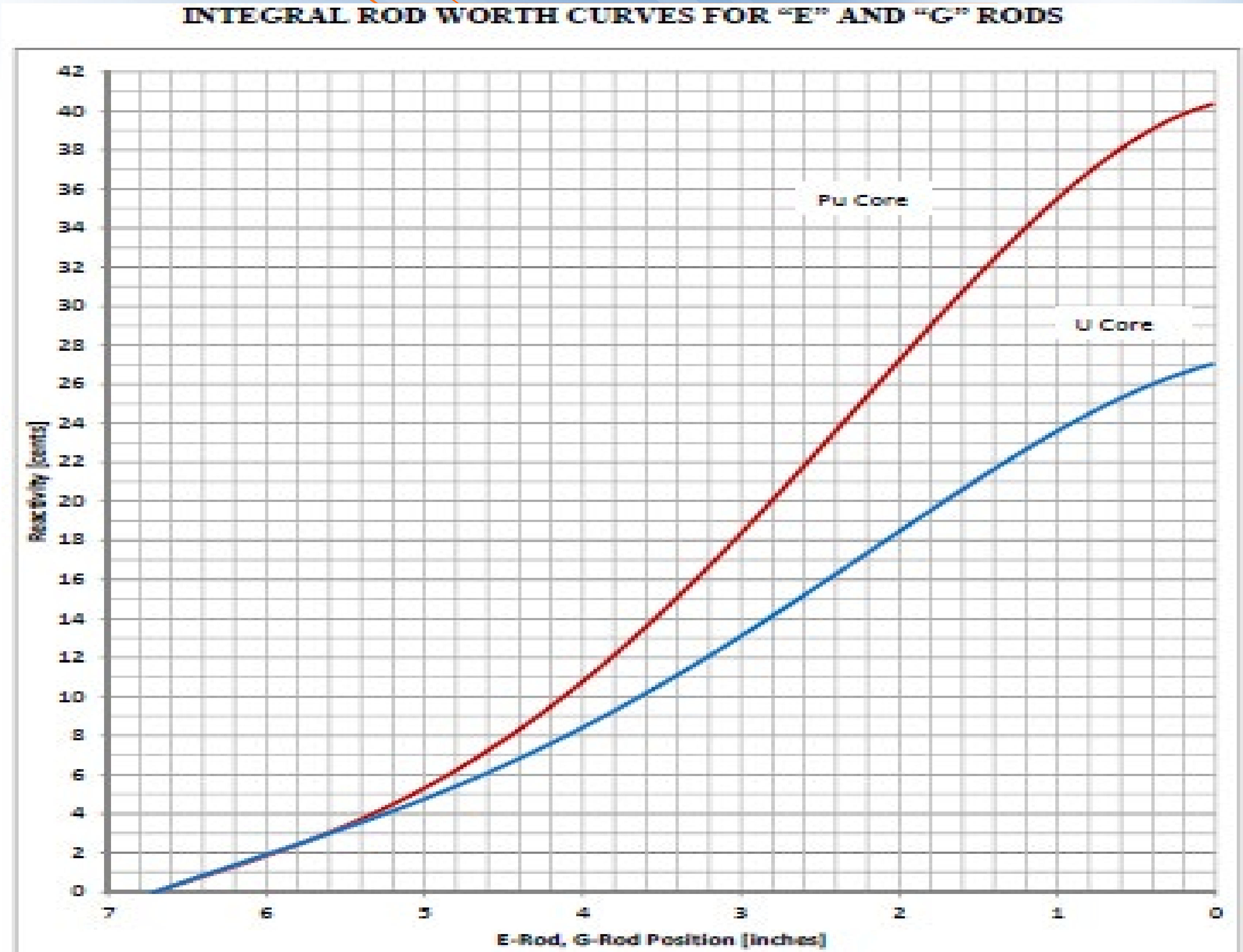
Interlocks

- A Block must be on in limit before B Block can be inserted.
- A Block and B Block must be on in limits before control rods E, F, or G can be inserted.
- All elements must be on out limit before reset is allowed.

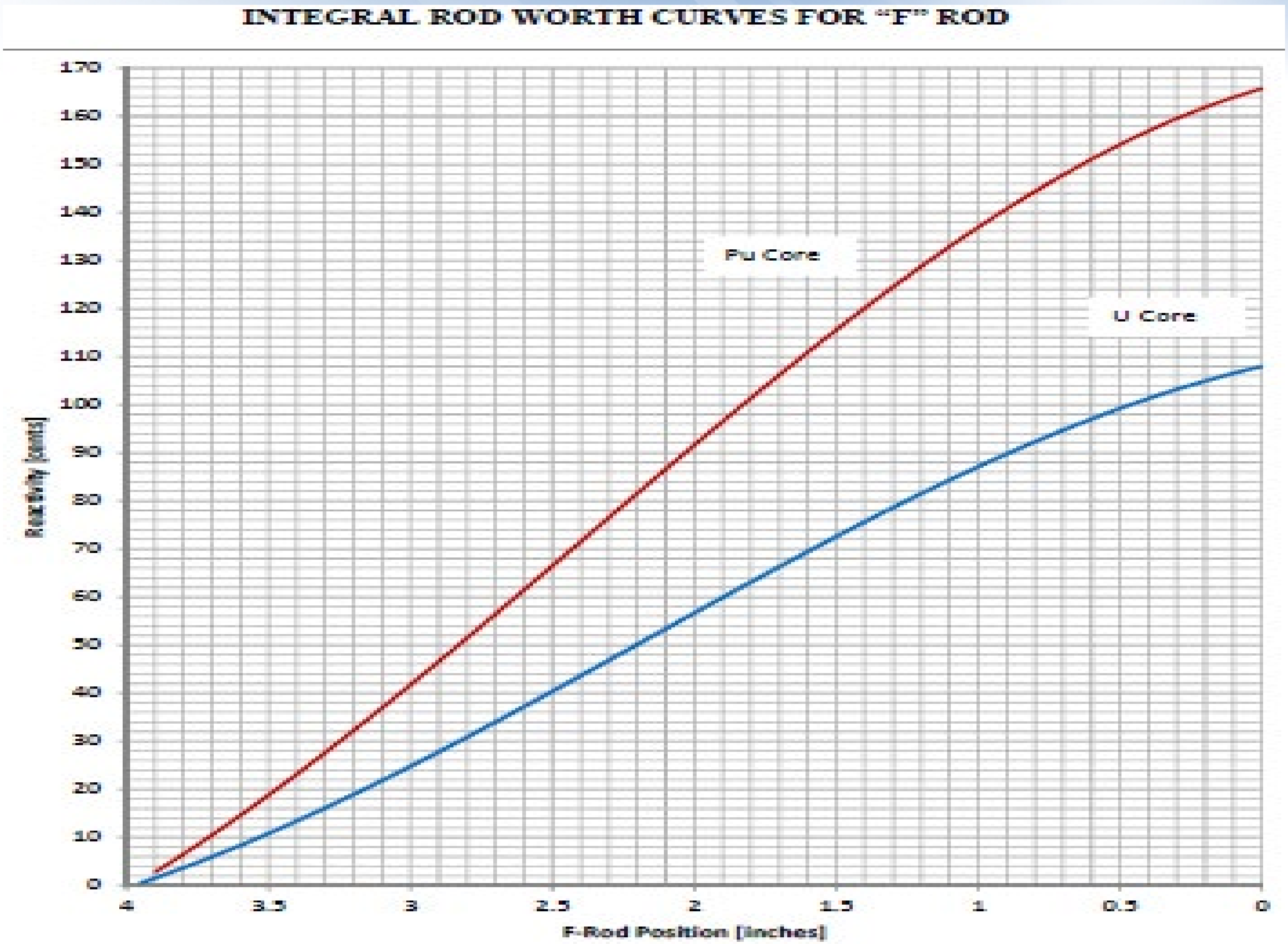
Dead-Man Feature

- Releasing a control element will stop the motion of the control element (except for A Block).
- If A Block is not on the in limit, it will automatically retract to the out limit.

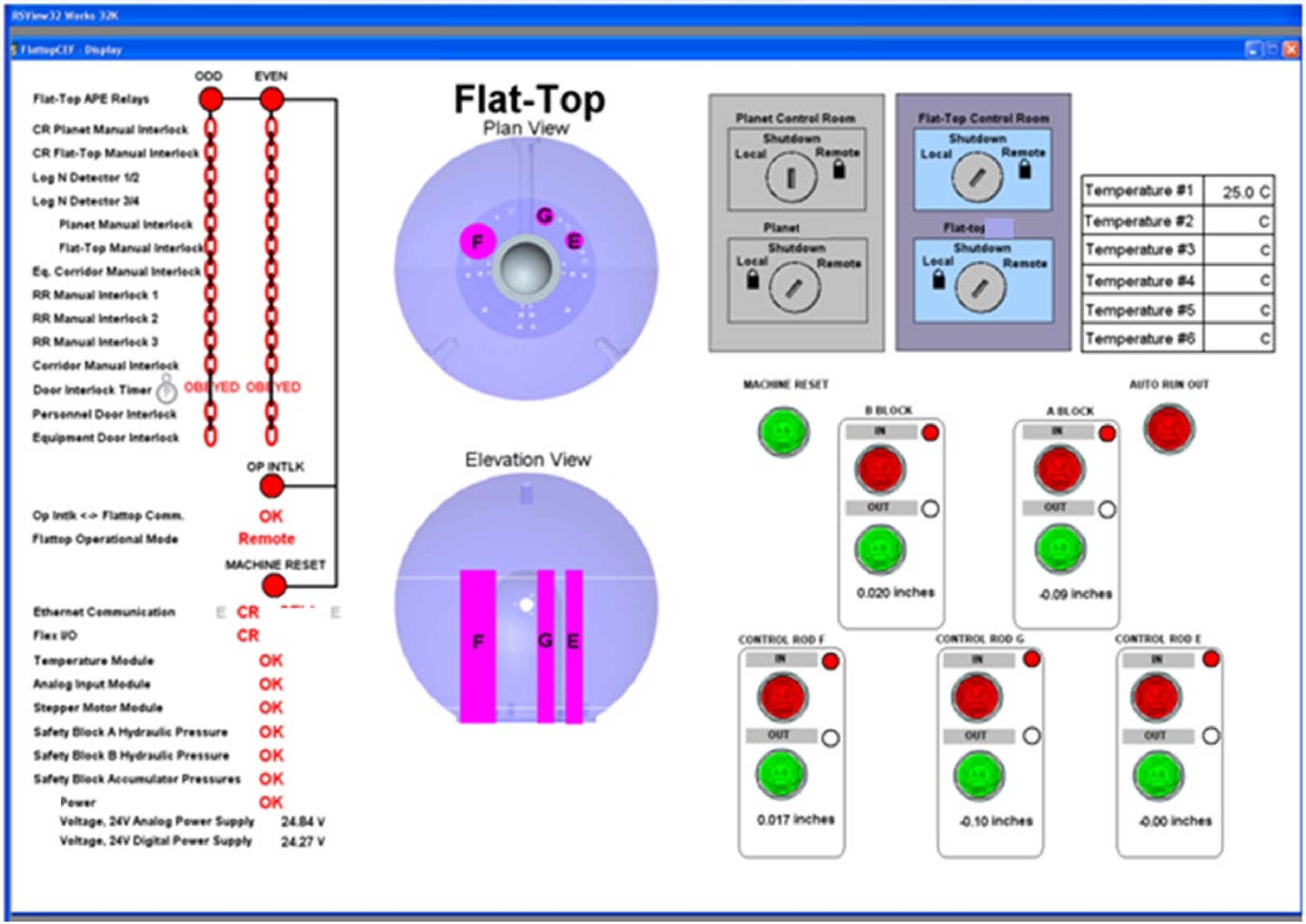
Flattop Control Rod Worths



Flattop Control Rod Worths



Flattop HMI Display



Flattop Local Control

- Local operation of Flattop is allowed, provided that
  - "…for any condition where a safety block must be moved with personnel in the room, with a core installed (e.g., alignment), power to the other safety block will be locked out";
  - local power lockouts are installed for each safety block actuator (similar to Godiva IV); and
  - the operators select "Move A Block" or "Move B Block" via the Local Control System as appropriate.

Inhour Equation for Flat-Top (Uranium)

$$\rho(\$) = \frac{l}{\beta_{eff} * T} + \sum_{i=1}^{12} \frac{\beta_i / \beta_{eff}}{1 + \lambda_i T}$$

$\rho(\$)$ is the reactivity in dollars.

β_{eff} / l is the Rossi-α at delayed critical.

T is the reactor period.

β_i / β_{eff} is the weighed relative abundance for ^{235}U for each of the six groups from fast fission and the weighed relative abundance for ^{238}U for each of the six groups from fast fission.

λ_i is the decay constant for ^{235}U for each of the six groups and the decay constant for ^{238}U for each of the six groups from fast fission.

Parameters Needed for the Inhour Equation

For the Flattop (Uranium)

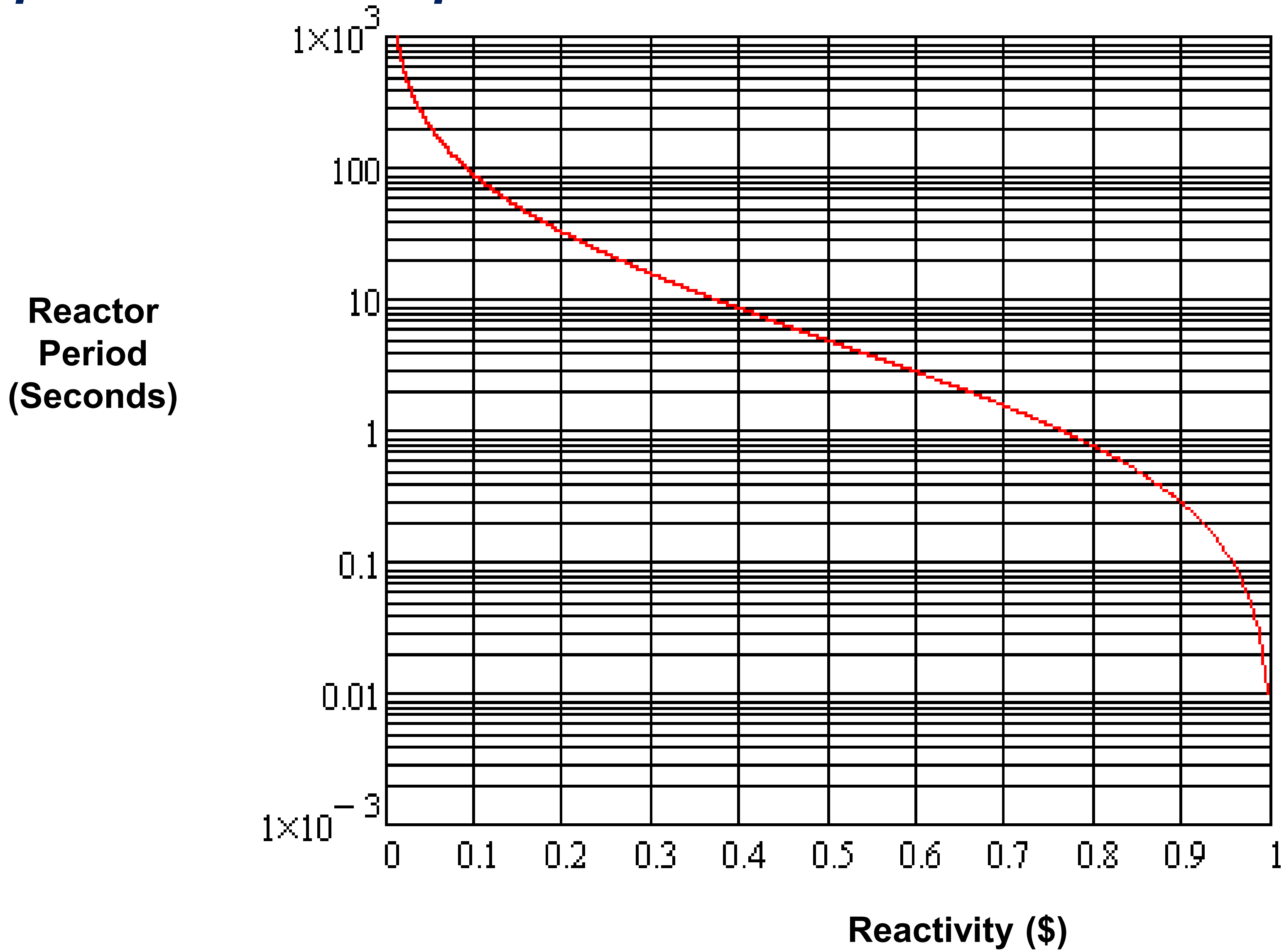
$\alpha(DC) = \beta/l = 3.8 \times 10^5\ s^{-1}$

82% of fissions occurred in ^{235}U and 18% in ^{238}U.

Decay Constants and Yields for ^{235}U and ^{238}U from Fast Fission.

Group Index, i	Decay Constant	Relative Abundance	Weighed Relative Abundance	Decay Constant	Relative Abundance	Weighed Relative Abundance
	^{235}U			^{238}U		
1	0.0127	0.038	0.0313	0.0132	0.013	0.002
2	0.0317	0.213	0.175	0.0321	0.137	0.024
3	0.115	0.188	0.155	0.139	0.162	0.028
4	0.311	0.407	0.335	0.358	0.388	0.068
5	1.40	0.128	0.105	1.41	0.225	0.039
6	3.87	0.026	0.021	4.02	0.075	0.013

Graphical Representation of the Inhour Equation for Flattop with the Uranium Core



Parameters Needed for the Inhour Equation

For the Flattop (Plutonium)

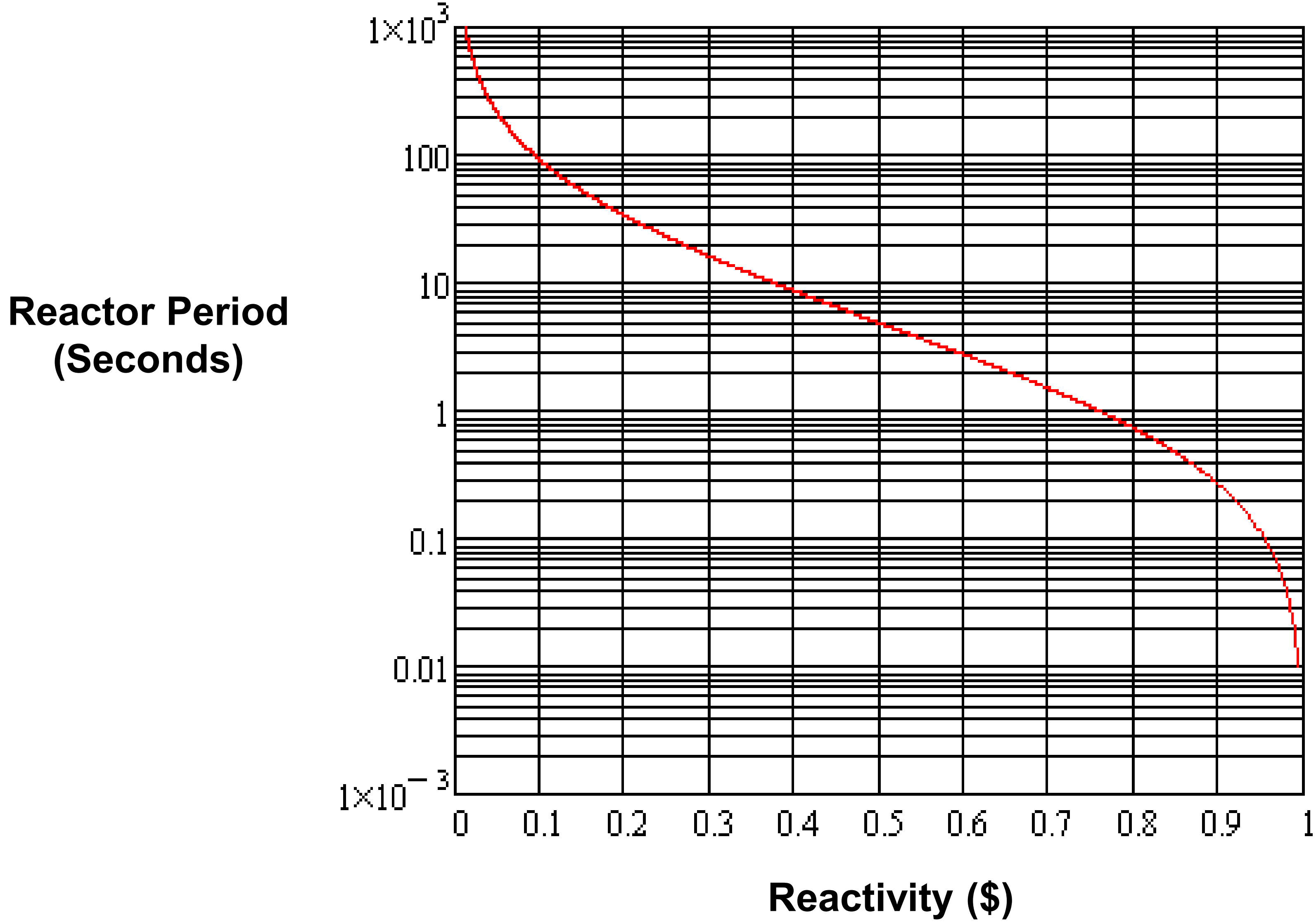
$\alpha(DC) = \beta/l = 2.28 \times 10^5\ s^{-1}$

66% of fissions occurred in ^{239}Pu and 34% in ^{238}U.

Decay Constants and Yields for ^{239}Pu and ^{238}U from Fast Fission

Group Index, i	Decay Constant	Relative Abundance	Weighed Relative Abundance	Decay Constant	Relative Abundance	Weighed Relative Abundance
	^{239}Pu			^{238}U		
1	0.0129	0.038	0.025	0.0132	0.013	0.005
2	0.0311	0.280	0.183	0.0321	0.137	0.047
3	0.134	0.216	0.155	0.139	0.162	0.056
4	0.331	0.328	0.215	0.358	0.388	0.134
5	1.26	0.103	0.067	1.41	0.225	0.078
6	3.21	0.035	0.023	4.02	0.075	0.026

Graphical Representation of the Inhour Equation for Flattop with the Plutonium Core



Temperature Coefficient of Reactivity

$$\frac{\Delta\rho}{\Delta T}(¢/°C)$$

Negative – temperature reactivity quench
Positive – autocatalytic or divergent reaction

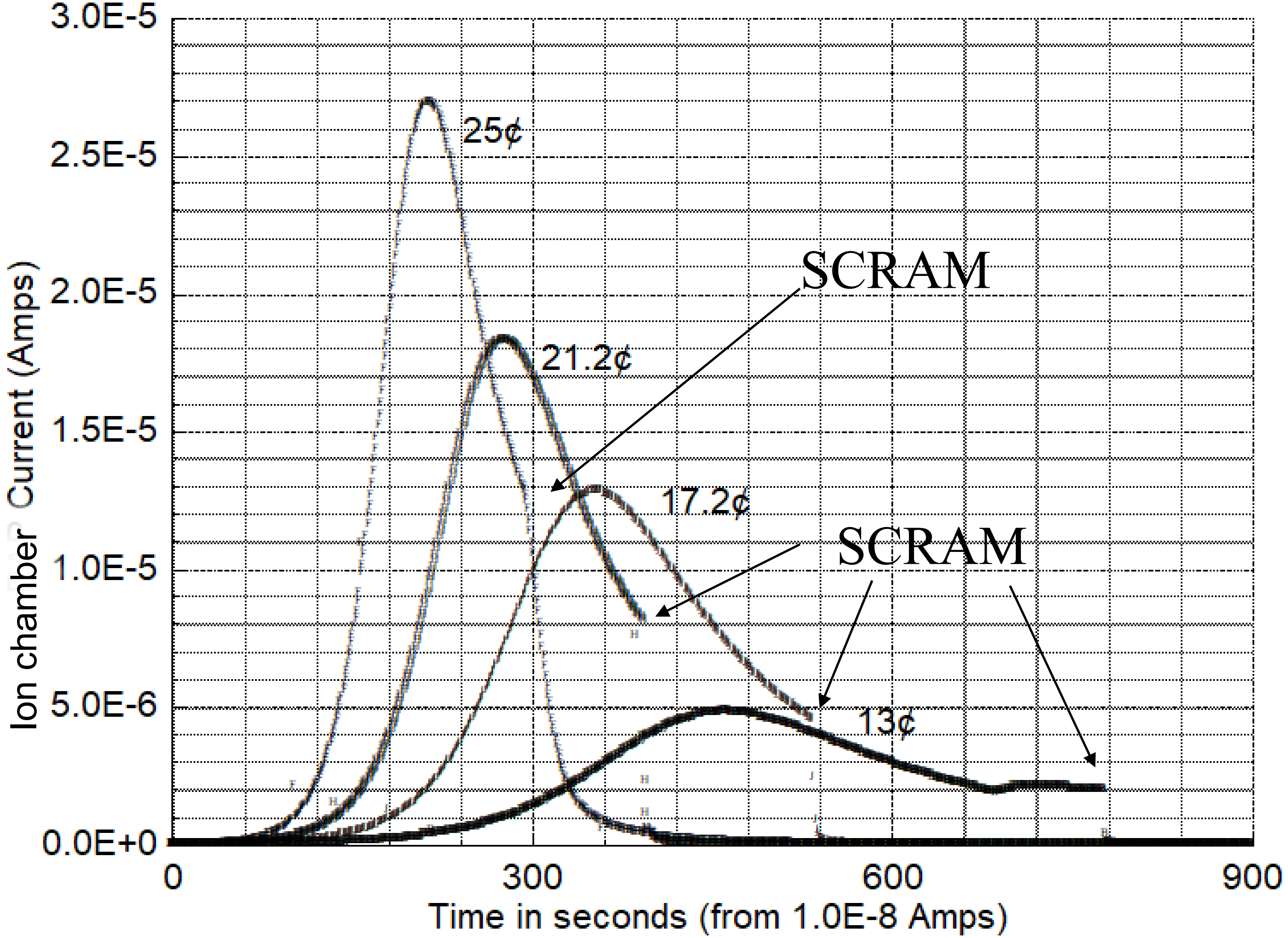
Assembly	Approx. Temp. Coeff.
Godiva IV, Big Ten, Flattop U	-0.3 (¢/°C)
Flattop delta-phase plutonium	-0.2(¢/°C)
SHEBA U(5) solution	-4.0 to -10.0 (¢/°C)
CNPS(U(20)O_2-C matrix	-1.2 (¢/°C)

Contributions from expansion, Doppler shifts, geometry changes

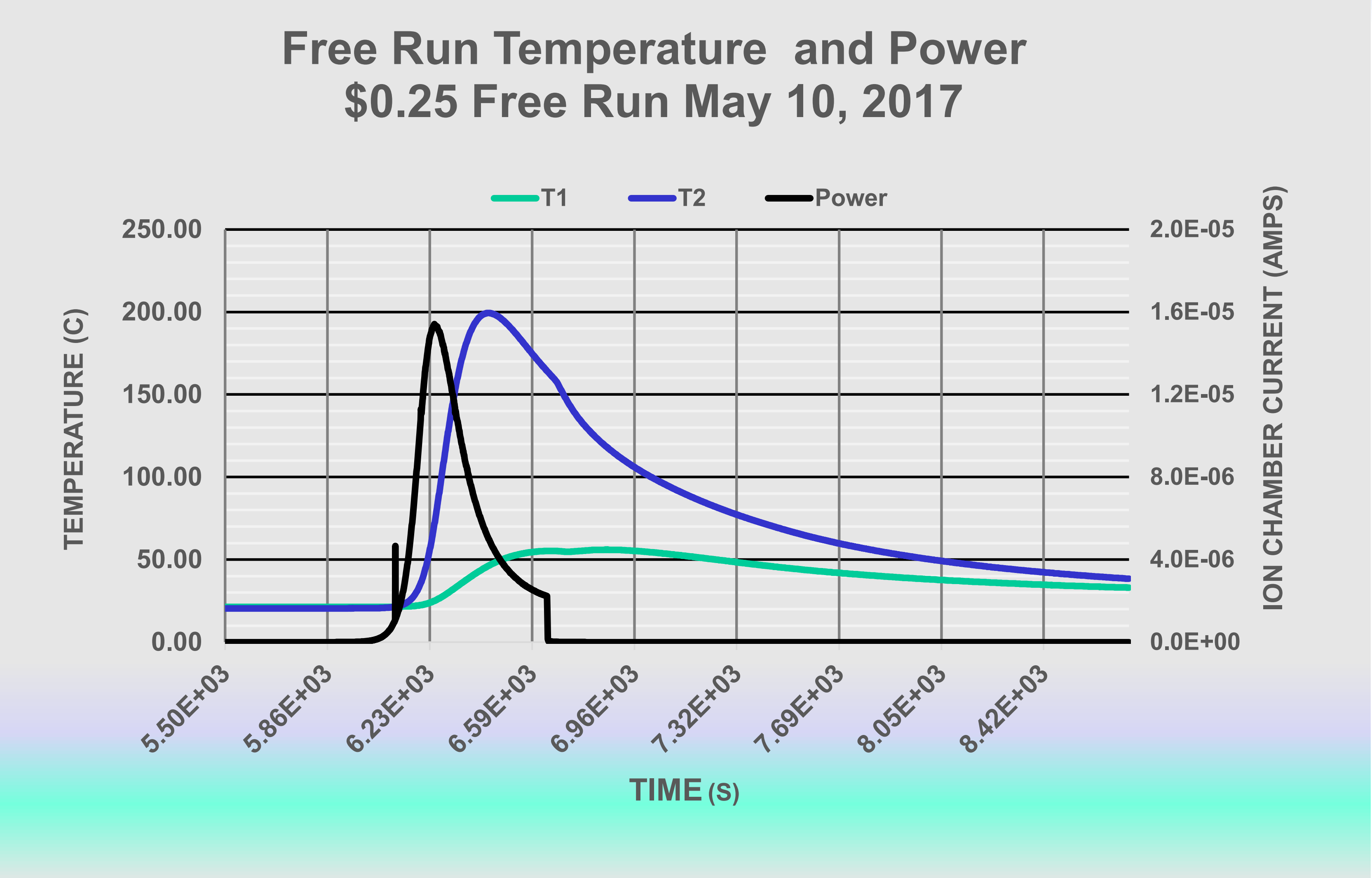
Basic Free-Run Operations Methodology

- Pre-op for remote operation
  - Verify configuration
- Verify excess reactivity
  - Establish DC
  - Insert all rods, measure excess reactivity
- Establish DC
- Insert free-run increment
- Withdraw B Block ~0.5 in.
  - Delayed neutron decay
- Insert B Block

Free-Run Data for Uranium Core



Free-Run Temperatures and Power



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2. R. Brewer and T. McLaughlin, “Uranium-235 Sphere Reflected by Normal Uranium Using FlatTop,” International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC/(95)03/II, HEU-MET-FAST-028.
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